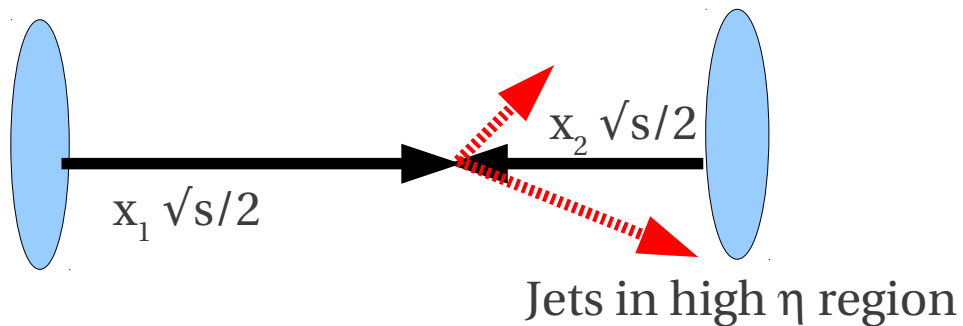


Forward jets and forward-central jets at CMS

Andrea Massironi
for the CMS collaboration

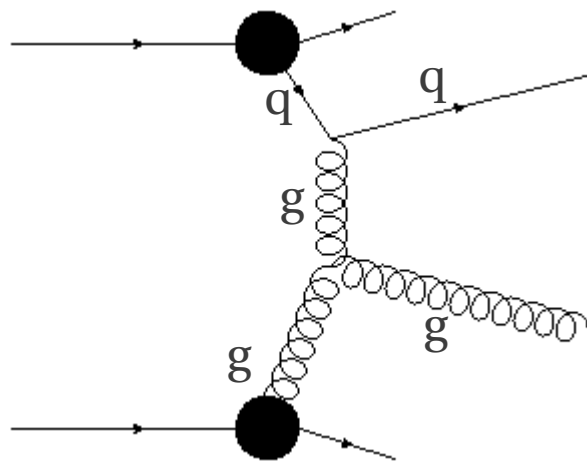
DIS2011
XIX International Workshop
on Deep-Inelastic Scattering and Related Subjects
11-15 April 2011, Newport News, VA (United States)



$$x = p_{\text{parton}} / p_{\text{proton}}$$

Forward jets allow to probe
x values as low as 10^{-5}
region sensitive to non-linear QCD effects

$$d\sigma(pp \rightarrow \text{jet}) = pdf(x_1, Q^2) \otimes pdf(x_2, Q^2) \otimes d\sigma(qg \rightarrow \text{jet})$$



$$x_2^{\min} = \frac{x_T e^{-\eta}}{2 - x_T e^{\eta}}$$

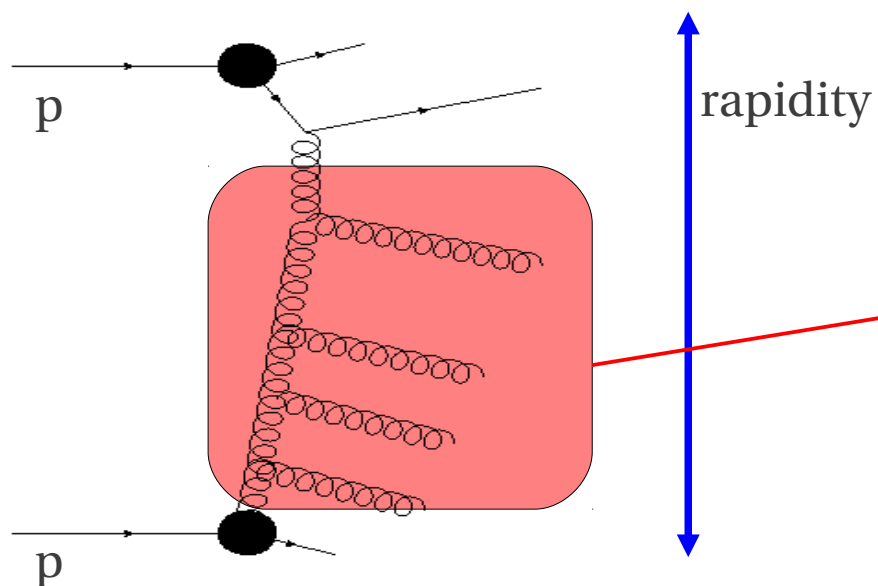
$$x_T = 2p_T / \sqrt{s}$$

$$p_T \sim 50 \text{ GeV}$$

$$\sqrt{s} = 7 \text{ TeV}$$

$$\eta \sim 5$$

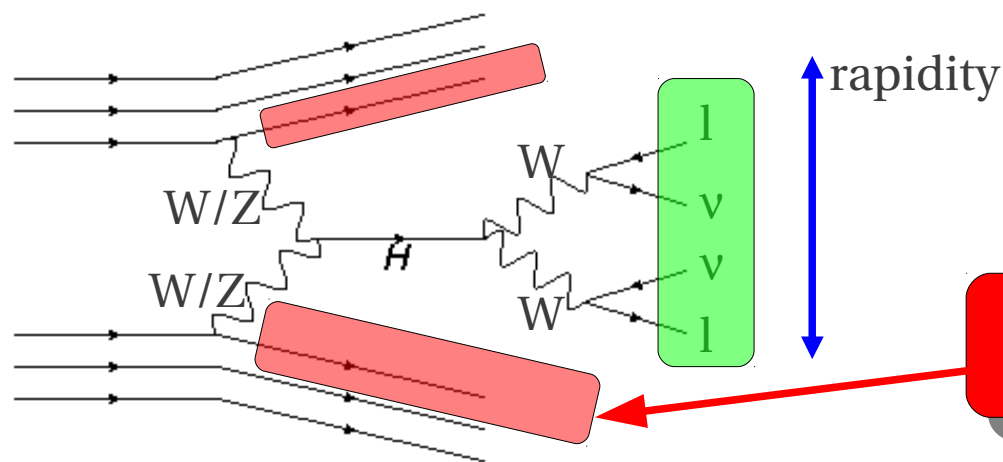
$$x_2^{\min} \sim 10^{-5}$$



Parton dynamics:

- DGLAP (p_T ordered emission)
- BFKL (x ordered emission)
- CCFM

First step to understand the topology of vector boson fusion Higgs production which is the key to understand EWSB



Forward – Backward jets

LHC
Large Hadron Collider

Proton-proton collider
 $\sqrt{s} = 7 \text{ TeV}$

High luminosity, up to $L \sim 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ in 2010

CMS
Compact Muon Solenoid

Large coverage calorimeter $|\eta| < 5.2$

Access a regime never investigated before

ECAL: Electromagnetic CALorimeter

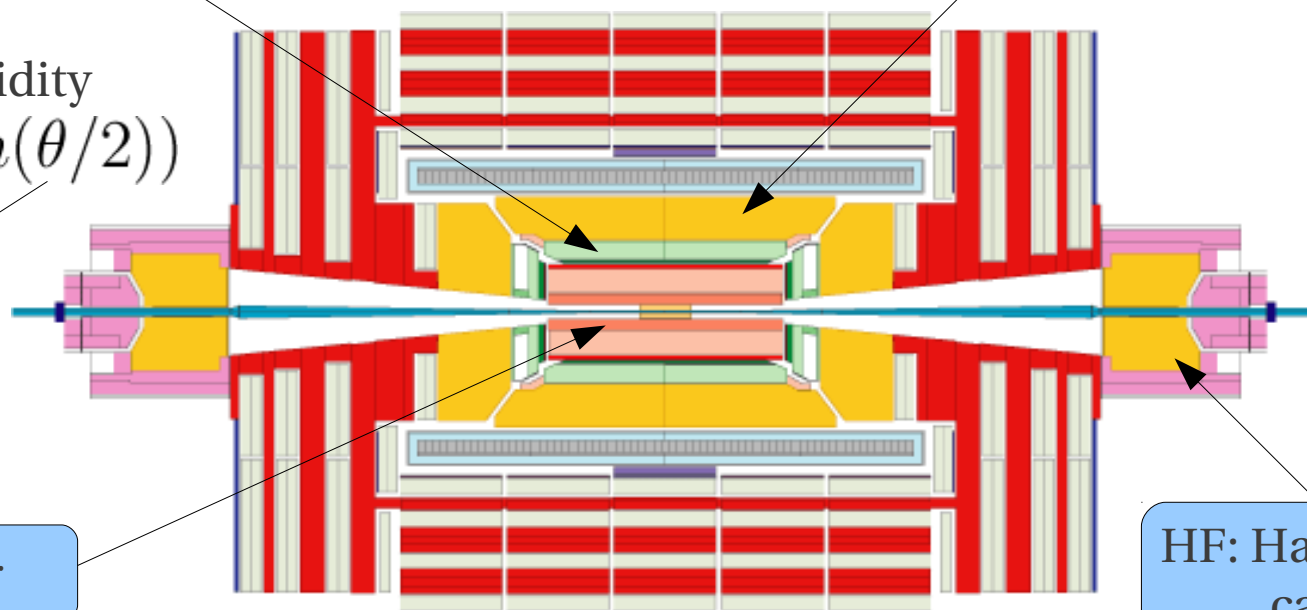
HCAL: Hadronic CALorimeter

pseudorapidity
 $\eta = -\ln(\tan(\theta/2))$

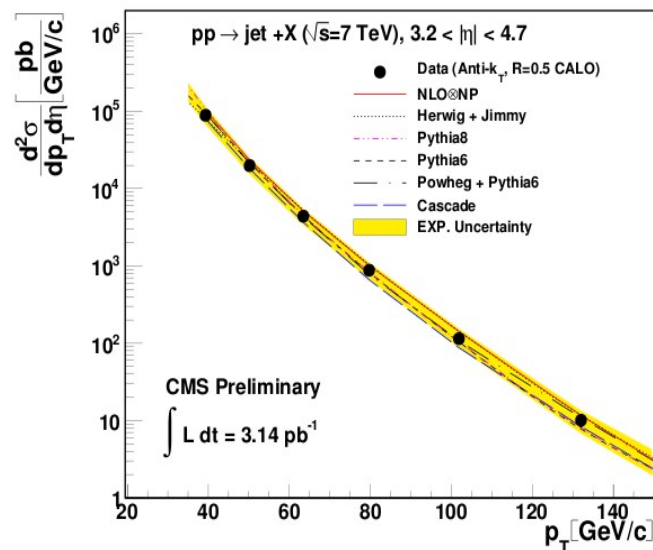
Azimuthal
angle w.r.t
beam axis

Tracker

HF: Hadronic Forward
calorimeters

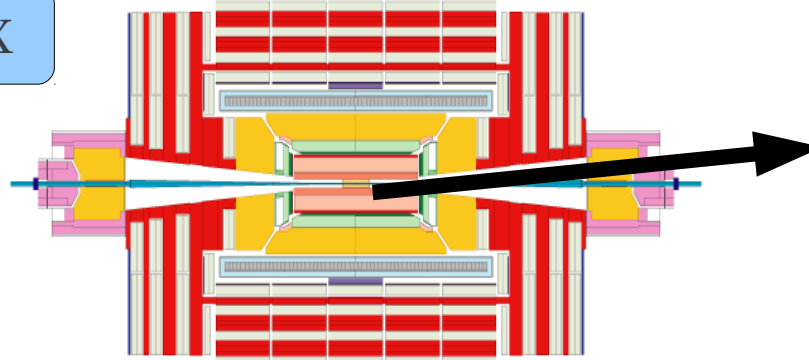


Inclusive Forward Jet Cross Section

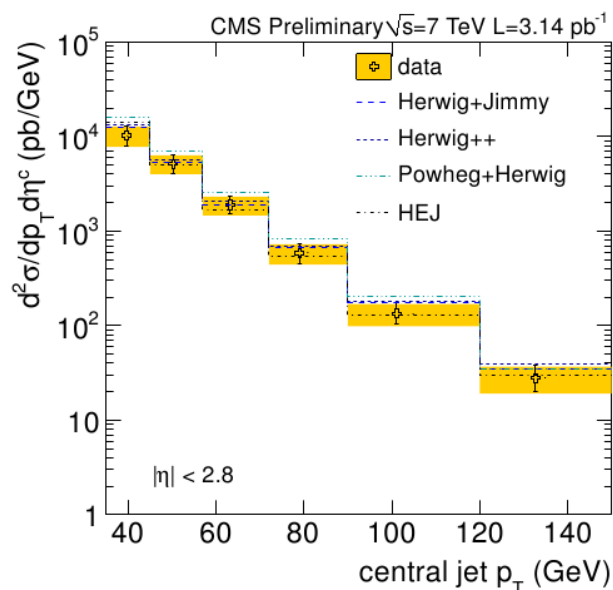
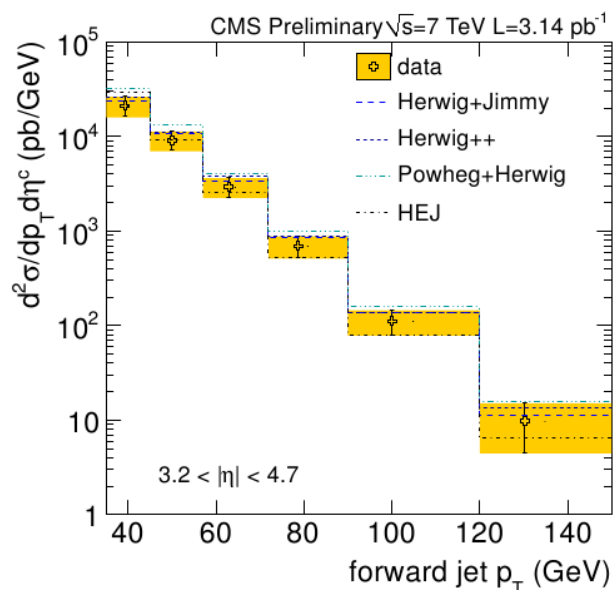


CMS PAS FWD-10-003

$pp \rightarrow \text{jet} + X$

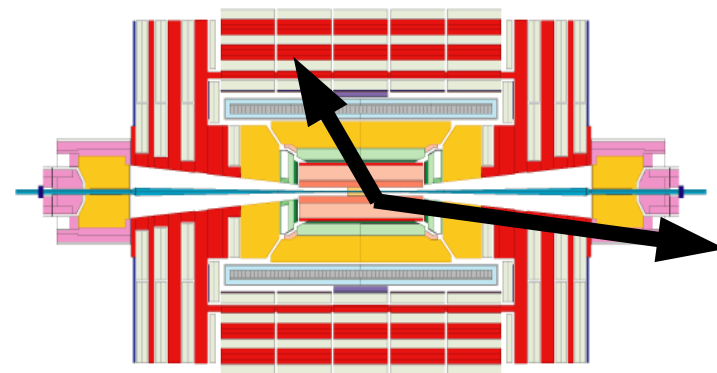


Simultaneous production of central and forward jets



CMS PAS FWD-10-006

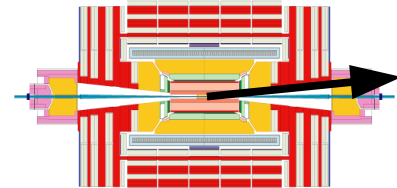
$pp \rightarrow \text{jet} + \text{jet}$



Detector level cross section of forward jets

- N_{jets} is the number of jets in a bin
- L is the integrated luminosity
- Δp_T and $\Delta \eta$ are the transverse momentum and rapidity bin sizes

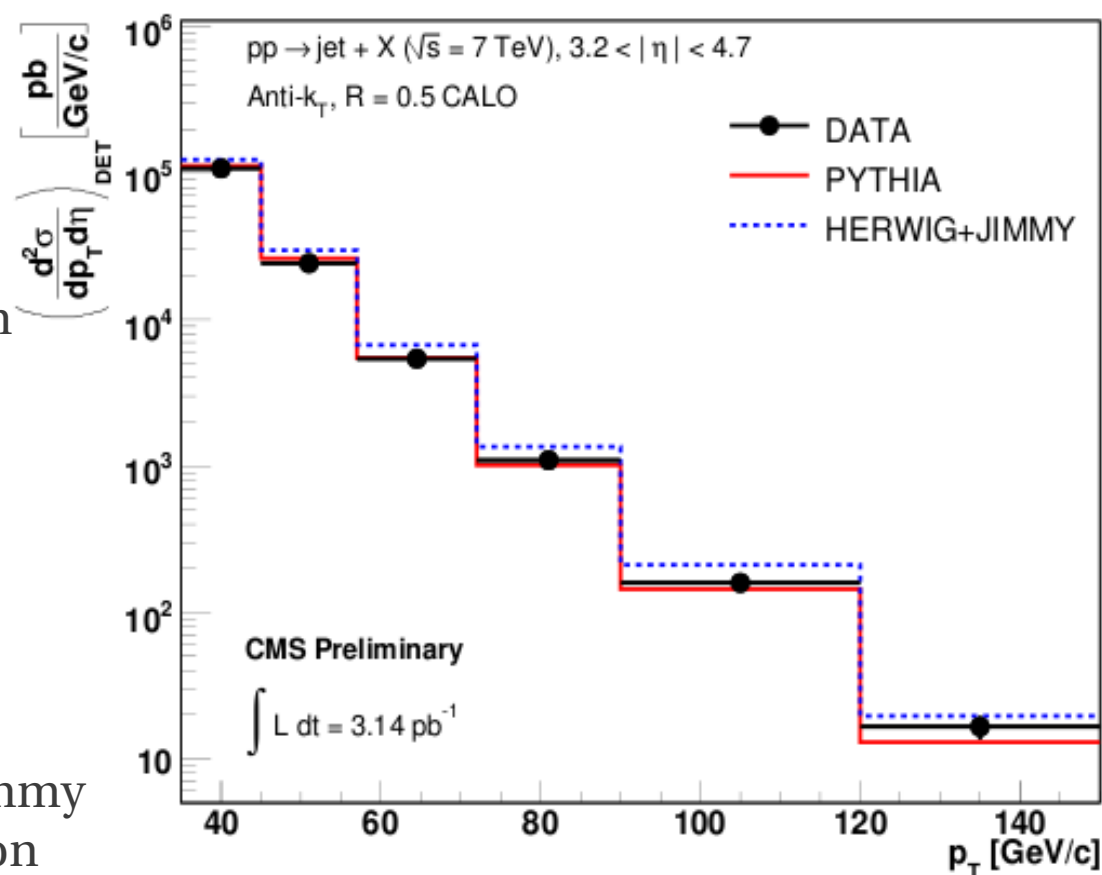
$pp \rightarrow \text{jet} + X$



$$\frac{d\sigma}{dp_T d\eta} = \frac{N_{\text{jets}}}{L \cdot \Delta p_T \Delta \eta}$$

- Anti- k_T ($R=0.5$) jet clustering algorithm
- Single jet with $p_T > 15$ GeV trigger
- Jet Identification criteria
- Fiducial acceptance $3.2 < |\eta| < 4.7$

Comparison with Pythia and Herwig+Jimmy
full CMS Monte Carlo events simulation

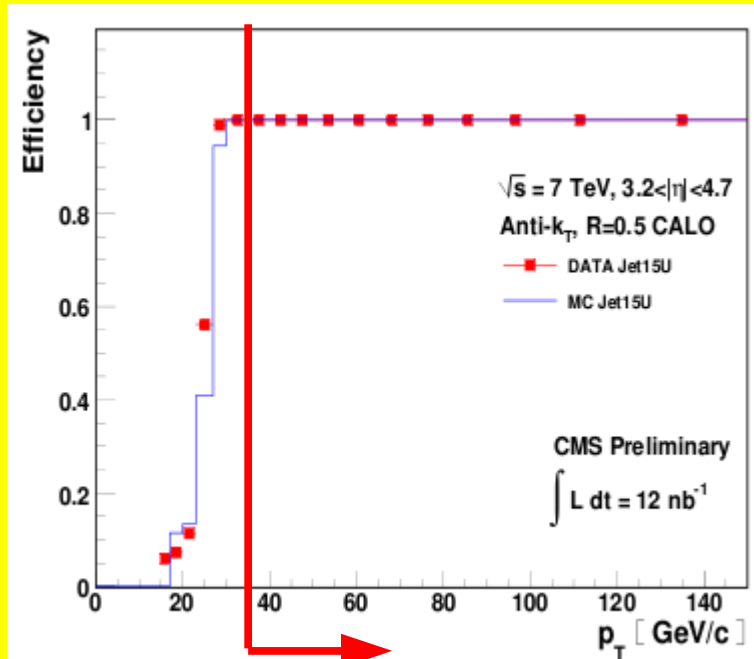


Hadron level cross section of forward jets

$$\frac{d\sigma}{dp_T d\eta} = \frac{C_{unfold} \cdot N_{jets}}{L \cdot \Delta p_T \Delta \eta}$$

- C_{unfold} is the bin-by-bin correction factor (trigger efficiency, event clean-up, jet-ID cuts and jet energy resolution)

Trigger efficiency ~ 100%



$p_T > 35 \text{ GeV}$

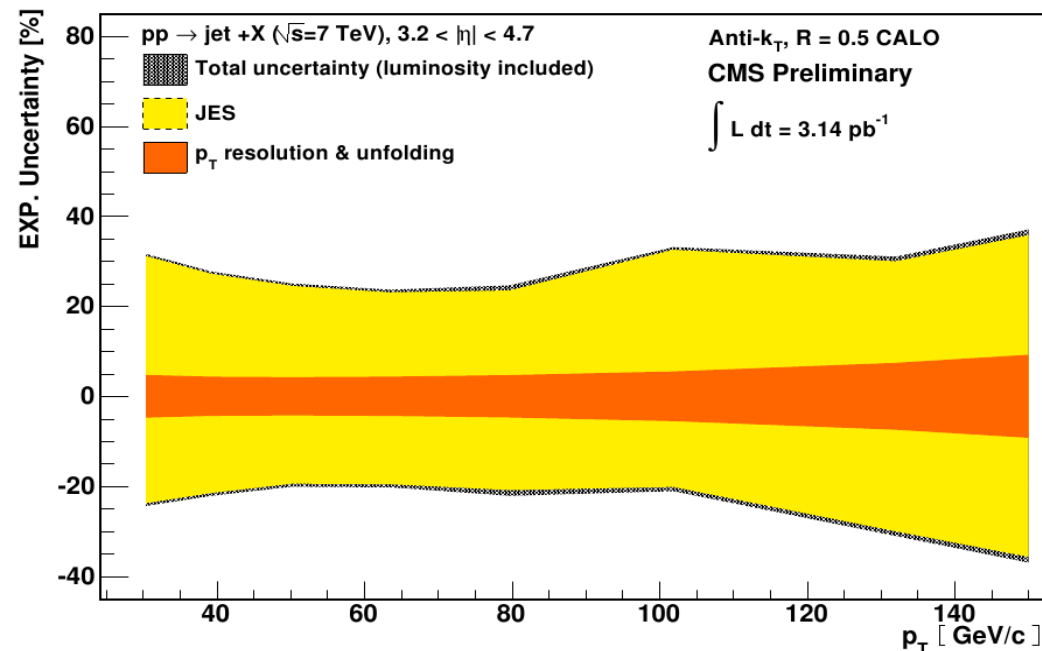
MC Bin-by-bin unfolding

$$C_{unfold} = \frac{N^{MC} (E_{had}^{MC} \in bin\ i)}{N^{MC} (E_{det}^{MC} \in bin\ i)}$$

Ansatz Bin-by-bin method

Convolution of hadron level distribution with a gaussian smearing that simulates jet energy resolution and fit to data

$$f(p_T) = N_0 \cdot p_t^{-\alpha} \cdot \left(1 - \frac{2 \cosh(y_{min}) p_T}{\sqrt{s}} \right)^{\beta} \exp(-\gamma/p_T)$$



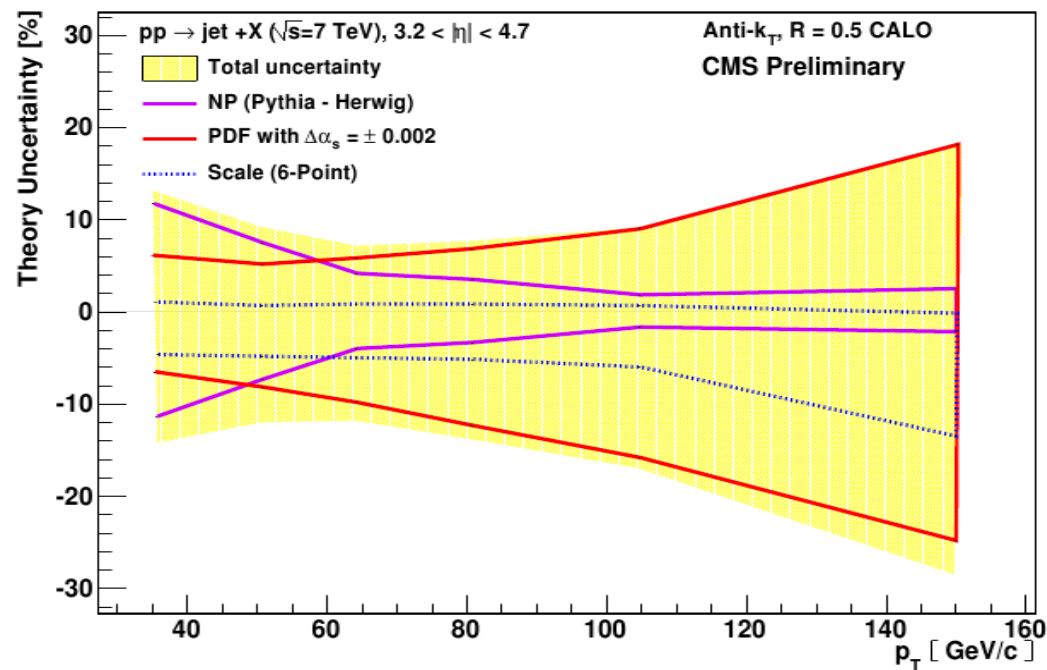
Experimental systematics:

absolute jet energy scale and PU $\sim 20/30\%$

p_T resolution $\sim 6\%$

Correction factor (different MC) $\sim 3\%$

Luminosity $\sim 4\%$



Theoretical uncertainties:

Hadronization and UE (Pythia and Herwig)

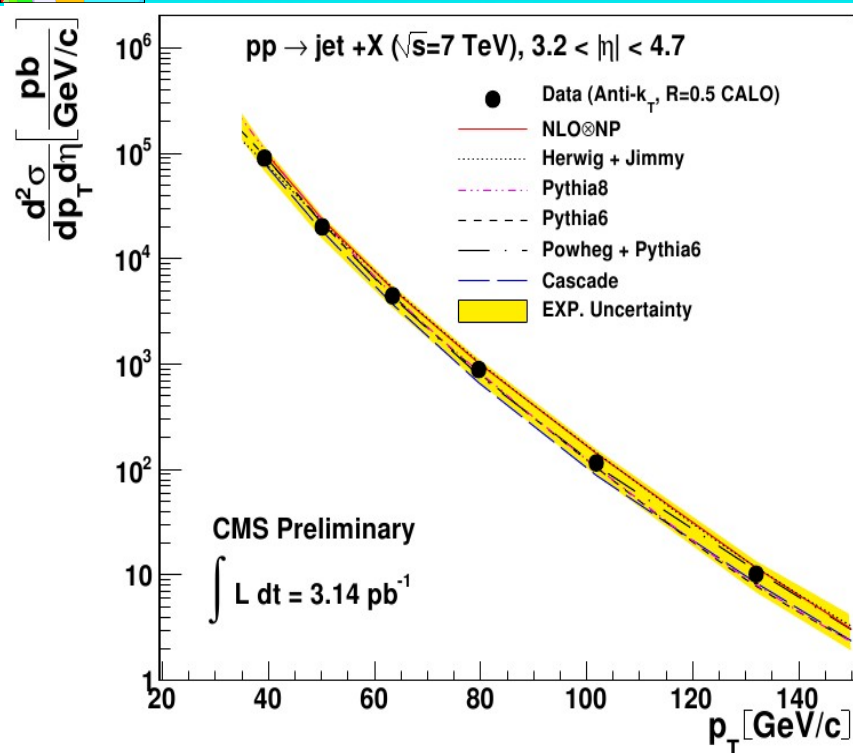
PDF uncertainty

α_s variation

Renormalization and factorization scales



Maximum envelope $\sim 10\%$

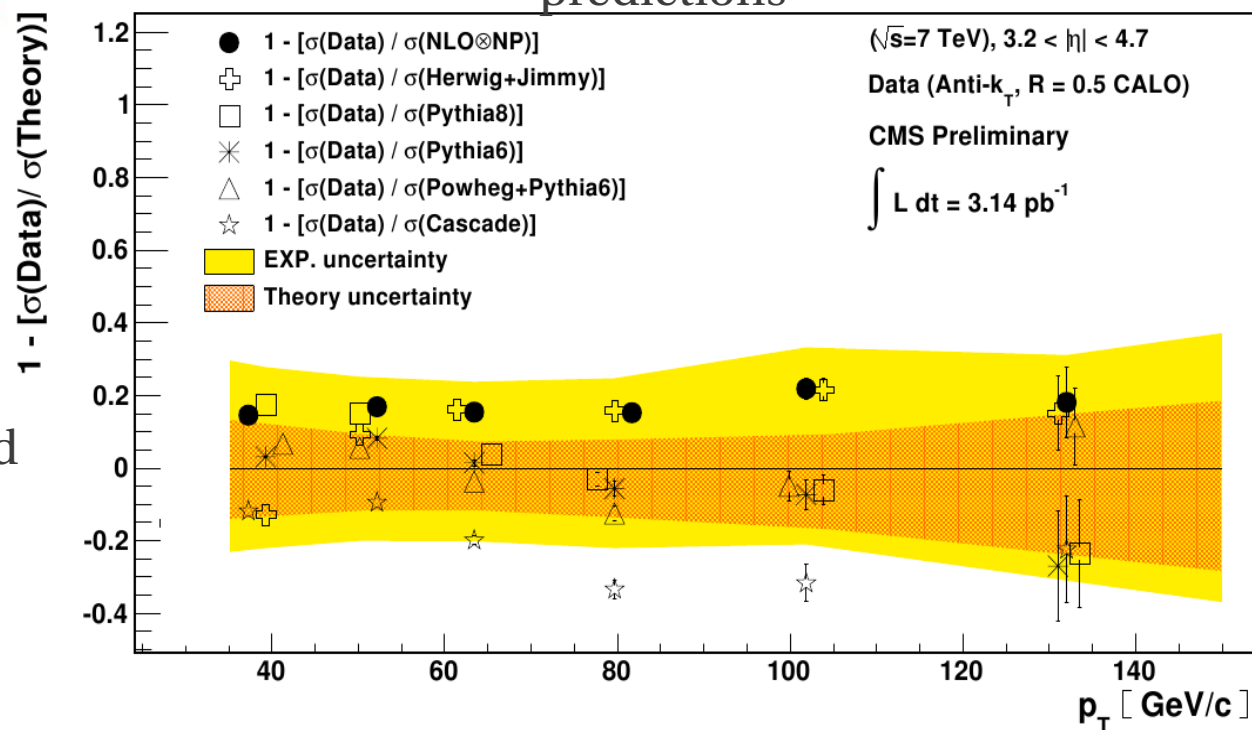


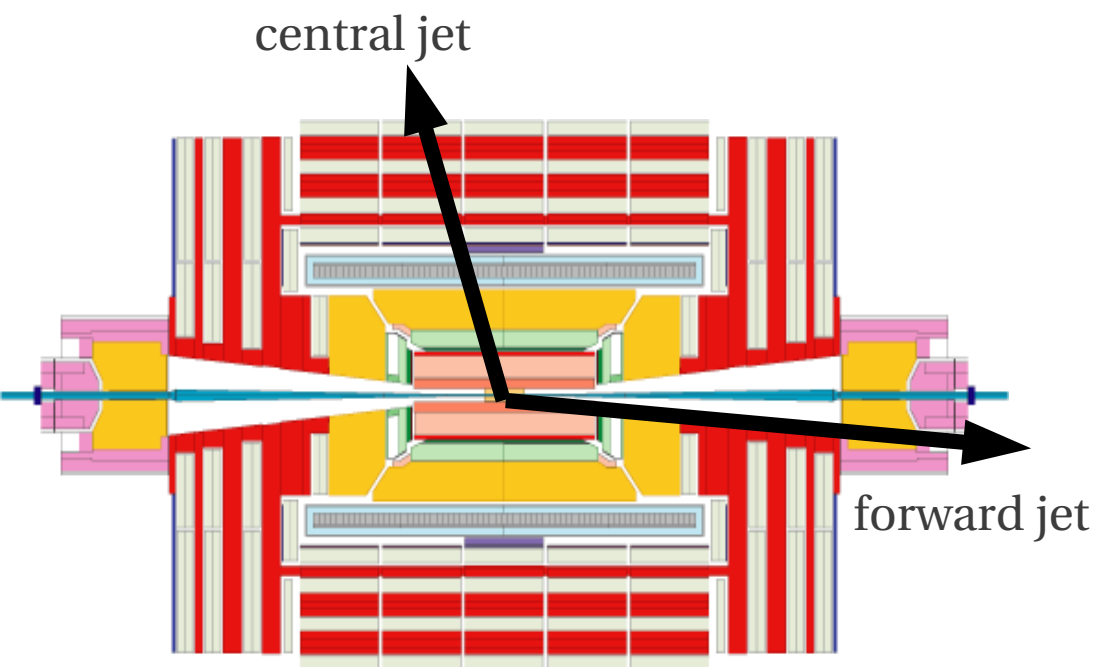
Within the current experimental and theoretical uncertainties, perturbative calculations reproduce globally well the measured forward jet cross section

$$\frac{d\sigma}{dp_T d\eta} = \frac{C_{unfold} \cdot N_{jets}}{L \cdot \Delta p_T \Delta \eta}$$

Inclusive jet cross section measured at forward pseudorapidities ($3.2 < |\eta| < 4.7$), fully corrected and unfolded

Comparison to various hadron-level theoretical predictions





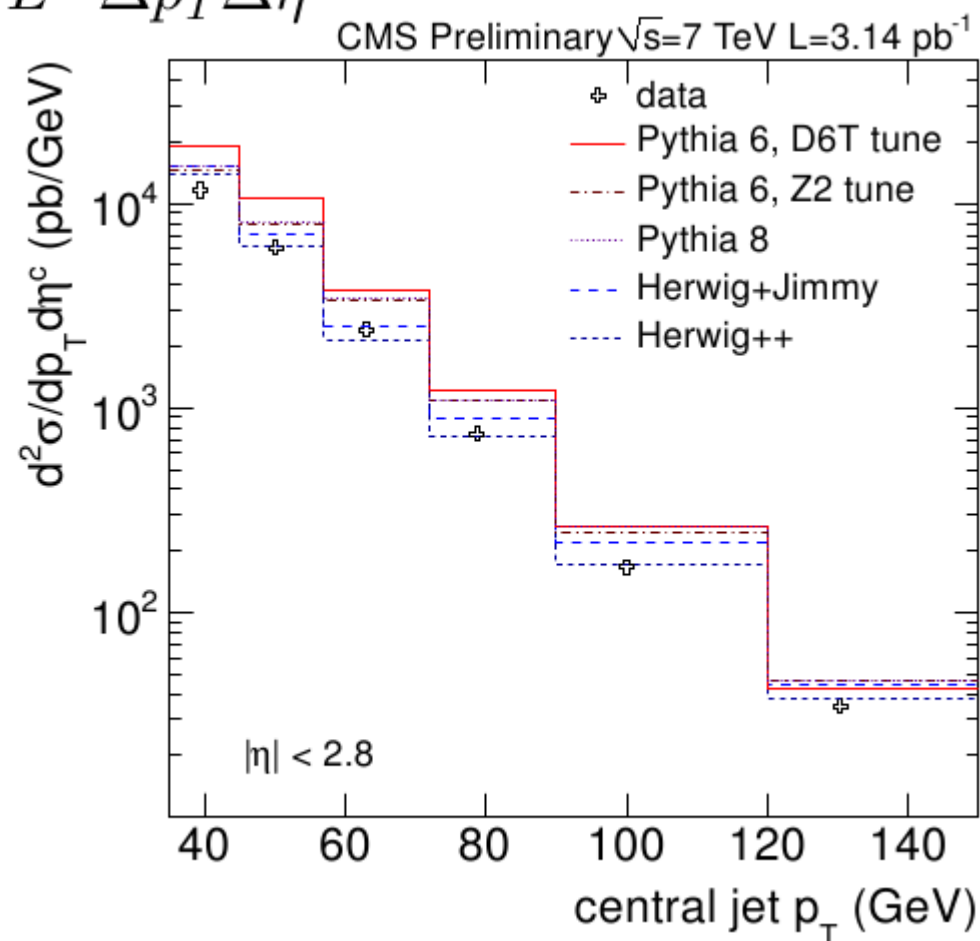
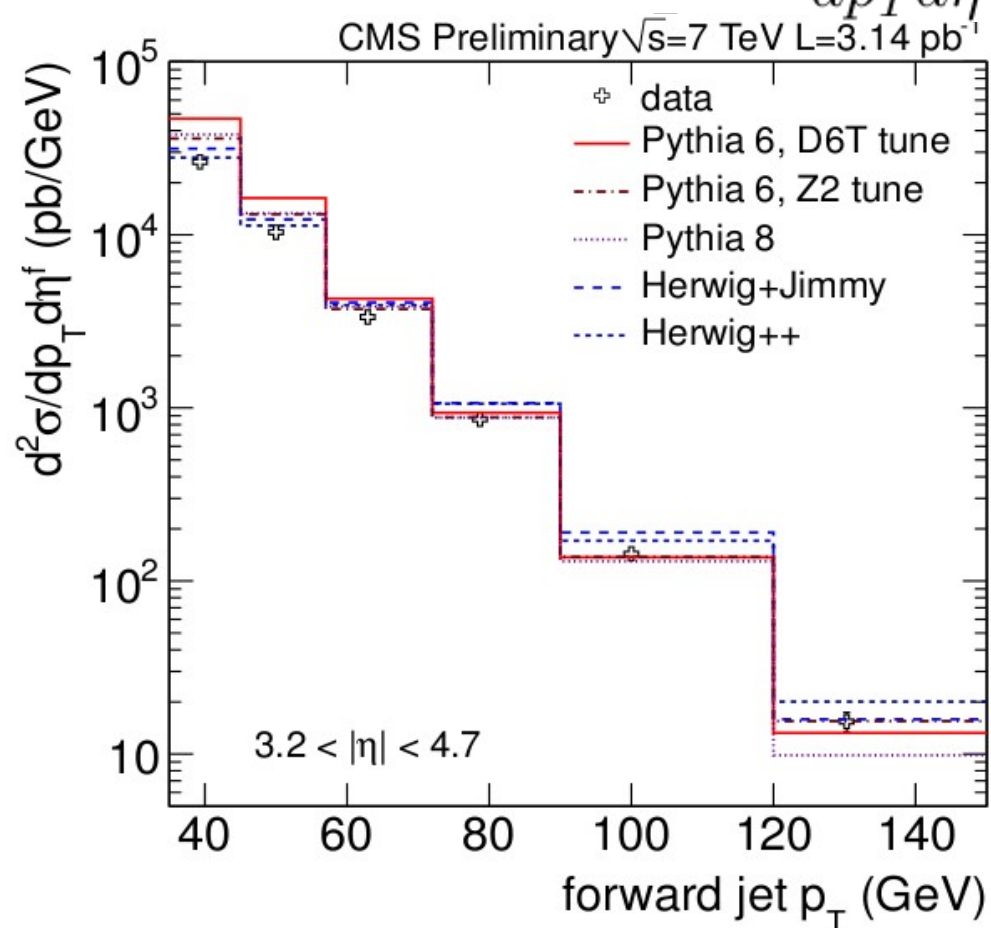
- Anti- k_T ($R=0.5$) jet clustering algorithm
- Di-jet with average $p_T > 15$ GeV trigger
- Central jet : $|\eta| < 2.8$
- Forward jet : $3.2 < |\eta| < 4.7$

One event is characterized by the presence of two jets:
the hardest one in the forward region and the hardest one in the central region

$$\frac{d\sigma}{dp_T^{\text{central}} d\eta^{\text{central}} dp_T^{\text{forward}} d\eta^{\text{forward}}} \rightarrow \begin{cases} \frac{d\sigma}{dp_T^{\text{central}} d\eta^{\text{central}}} \\ \frac{d\sigma}{dp_T^{\text{forward}} d\eta^{\text{forward}}} \end{cases}$$

Detector level cross section of forward / central jets

$$\frac{d\sigma}{dp_T d\eta} = \frac{N_{jets}}{L \cdot \Delta p_T \Delta \eta}$$



Comparison with Pythia and Herwig
full CMS Monte Carlo events simulation at detector level

Hadron level cross section of forward / central jets

Reweighted MC Bin-by-bin unfolding

$$\frac{d\sigma}{dp_T d\eta} = \frac{C_{unfold} \cdot N_{jets}}{L \cdot \Delta p_T \Delta \eta}$$

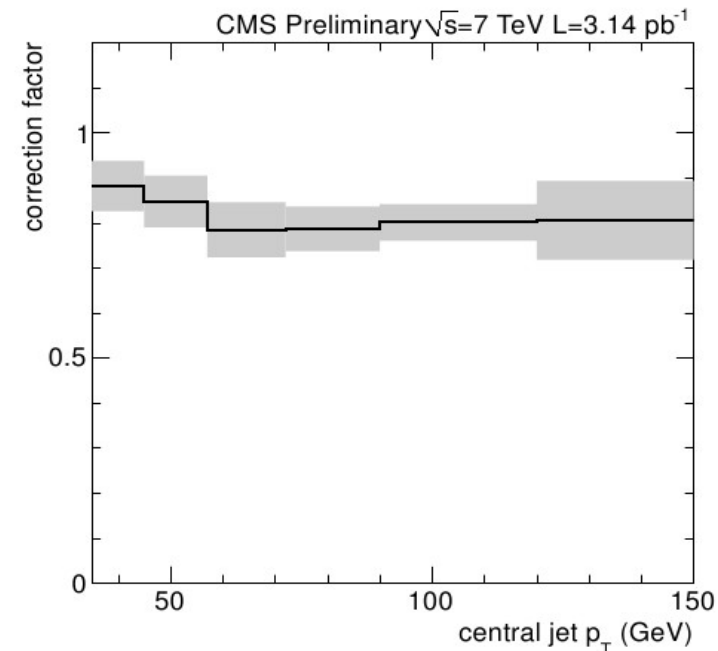
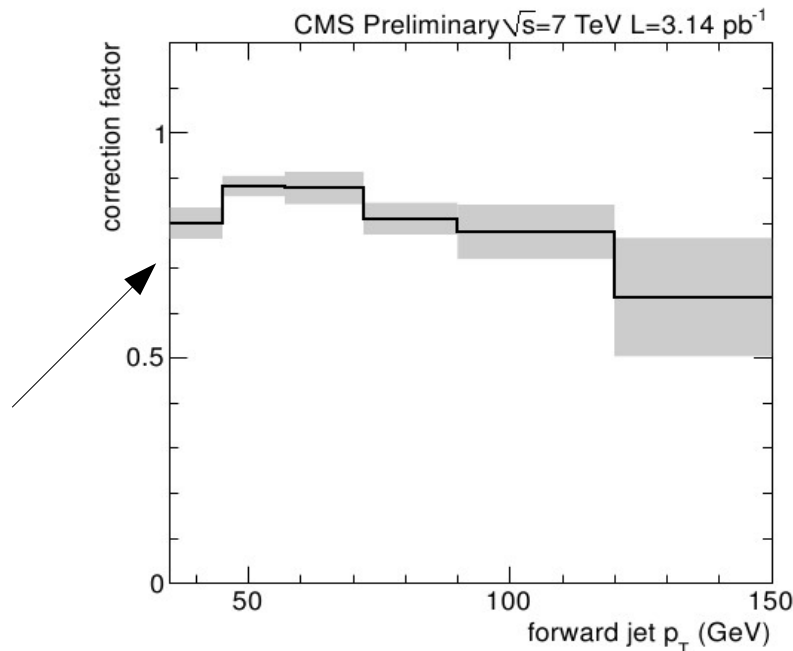
Bin-by-bin correction factor \rightarrow take into account for detector effects

Monte Carlo spectrum at hadron level reweighted \rightarrow overlap to the data at detector level

Bin-by-bin unfolding coefficients $C_{unfold} = \frac{N^{MC} (E_{had}^{MC} \in bin\ i)}{N^{MC} (E_{det}^{MC} \in bin\ i)}$

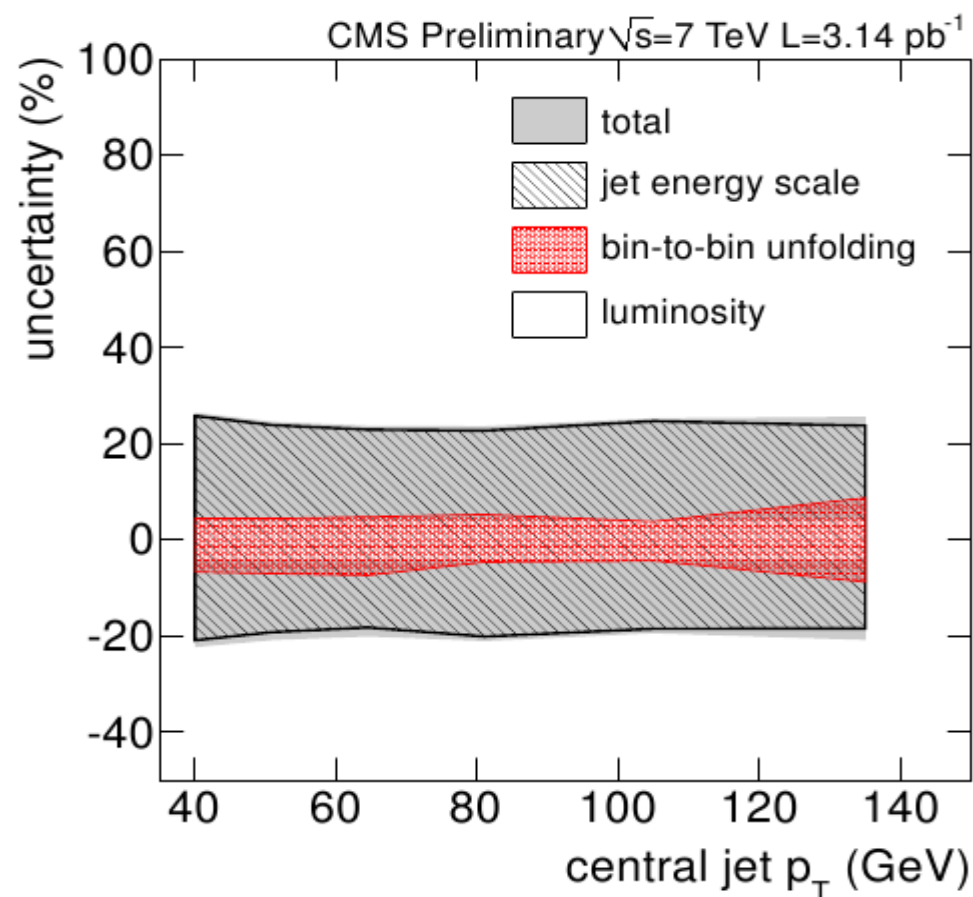
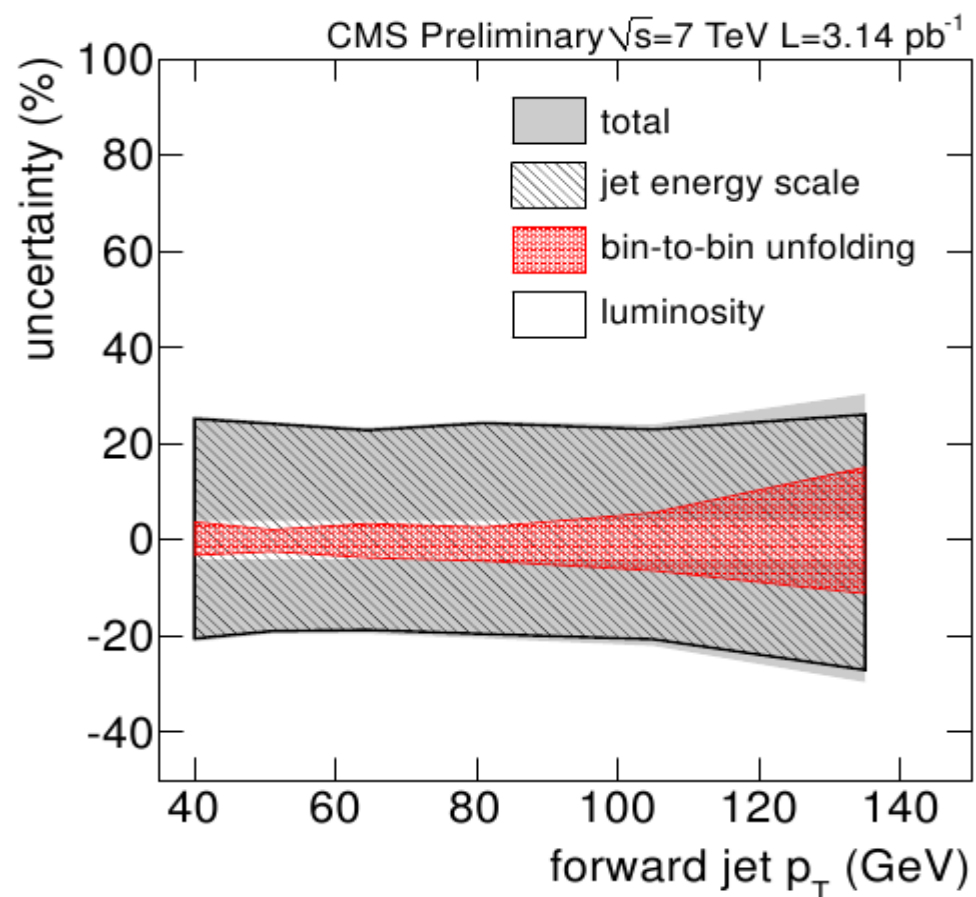
Systematic due to
bin-by-bin unfolding

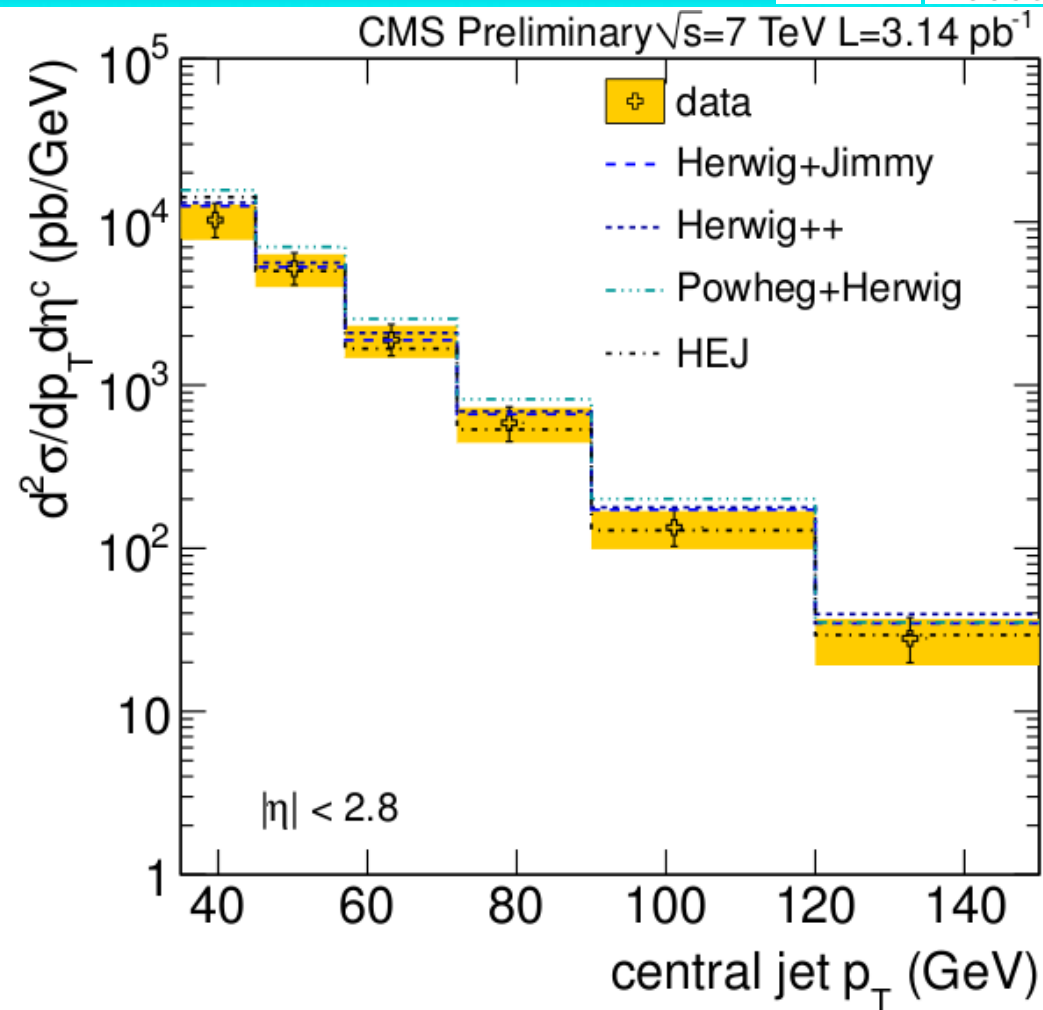
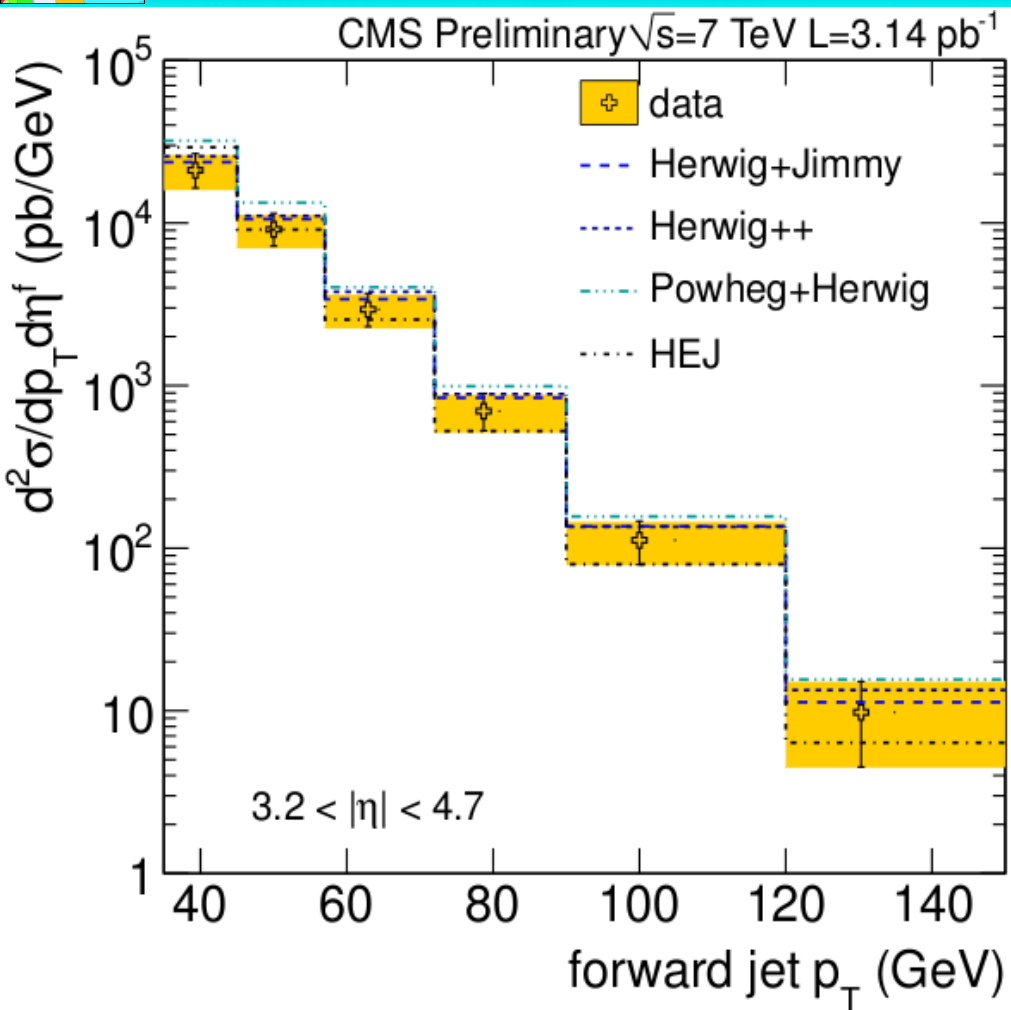
Envelope of
correction factors
from different MC



Experimental systematics:

absolute jet energy scale	$\sim 25\%$
p_T resolution and unfolding method	$\leq 5\%$
PU (1 or more than 1 Primary Vertex)	$\sim 5\%$
Luminosity	$\sim 4\%$





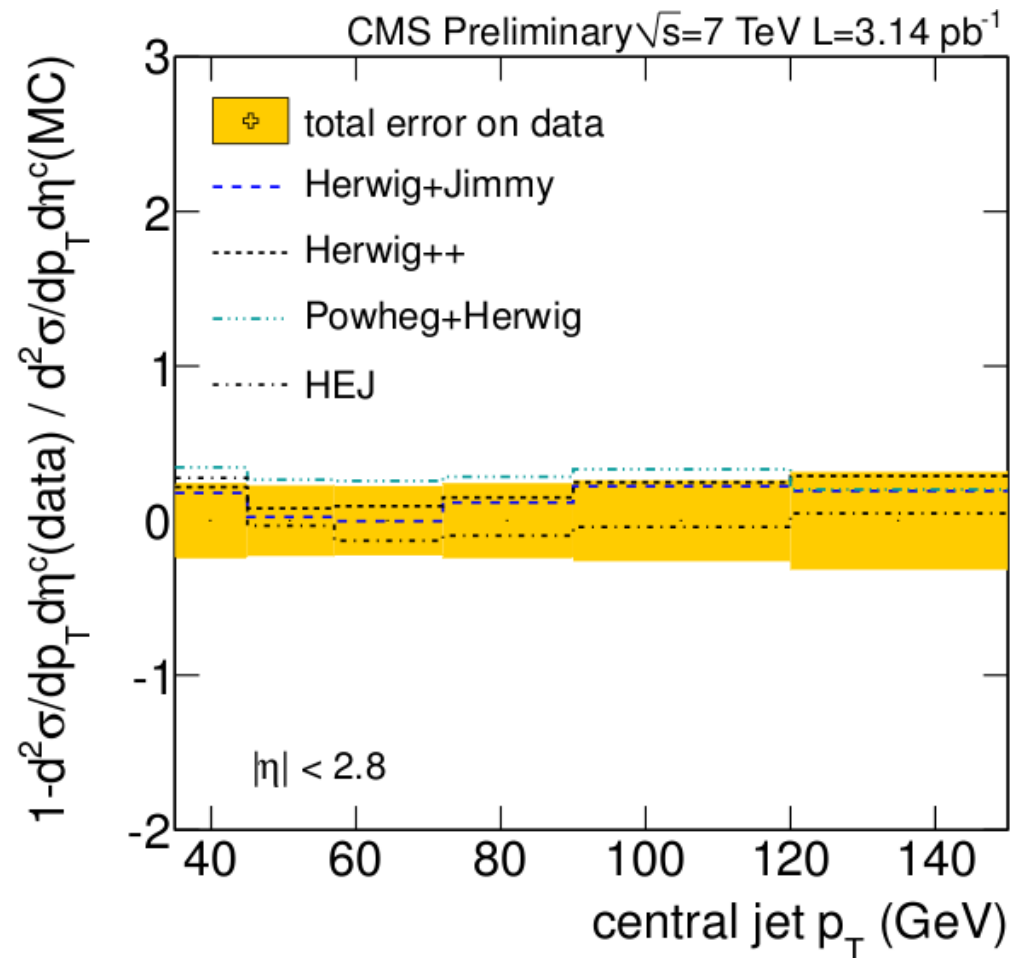
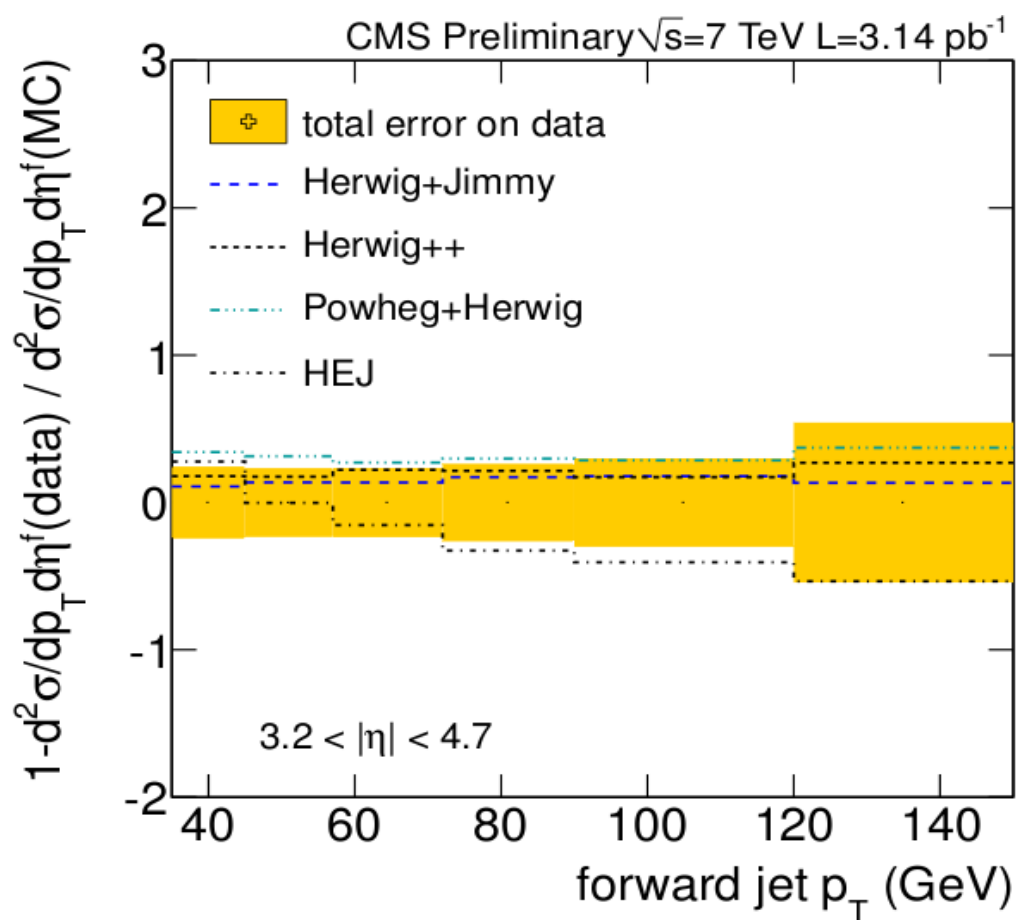
Comparison to various hadron-level theoretical predictions

$$\frac{d\sigma}{dp_T d\eta} = \frac{C_{unfold} \cdot N_{jets}}{L \cdot \Delta p_T \Delta \eta}$$

Some differences in p_T spectra due to the request of simultaneous production of a jet in the forward region and one in the central region

Comparison to various hadron-level theoretical predictions

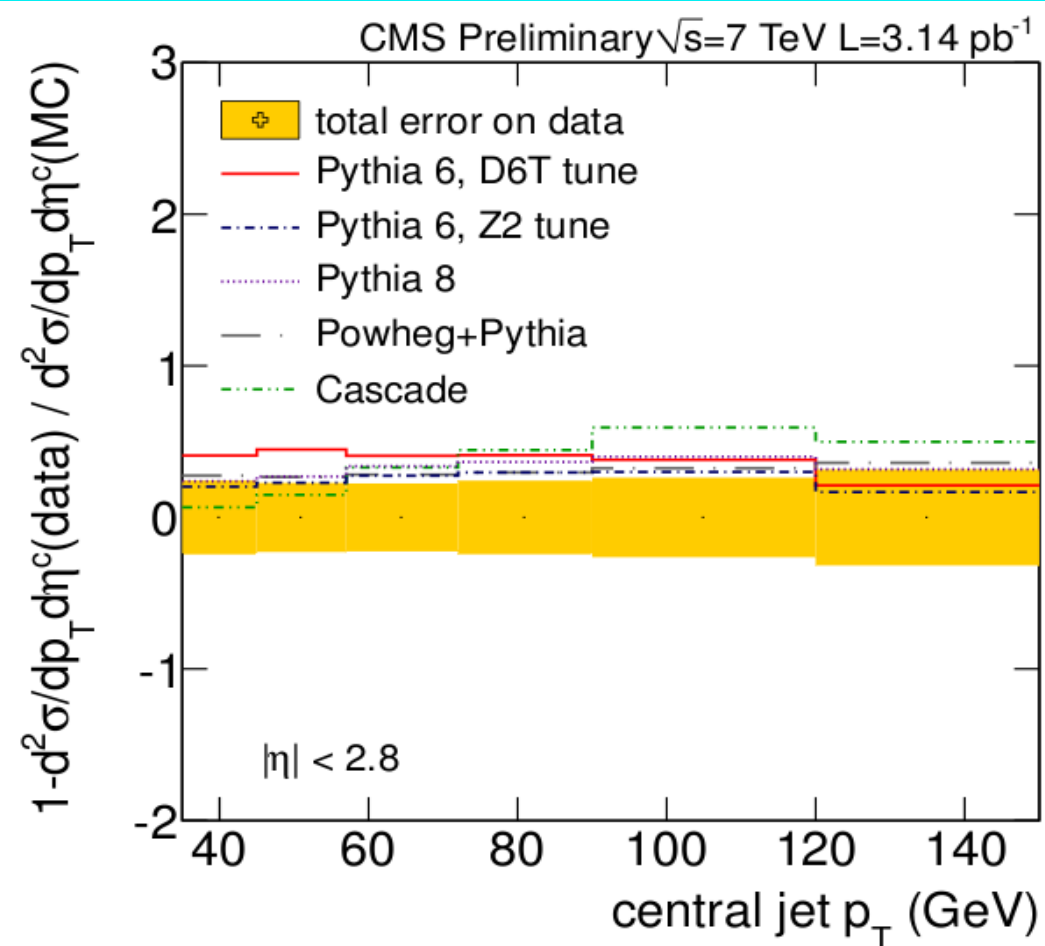
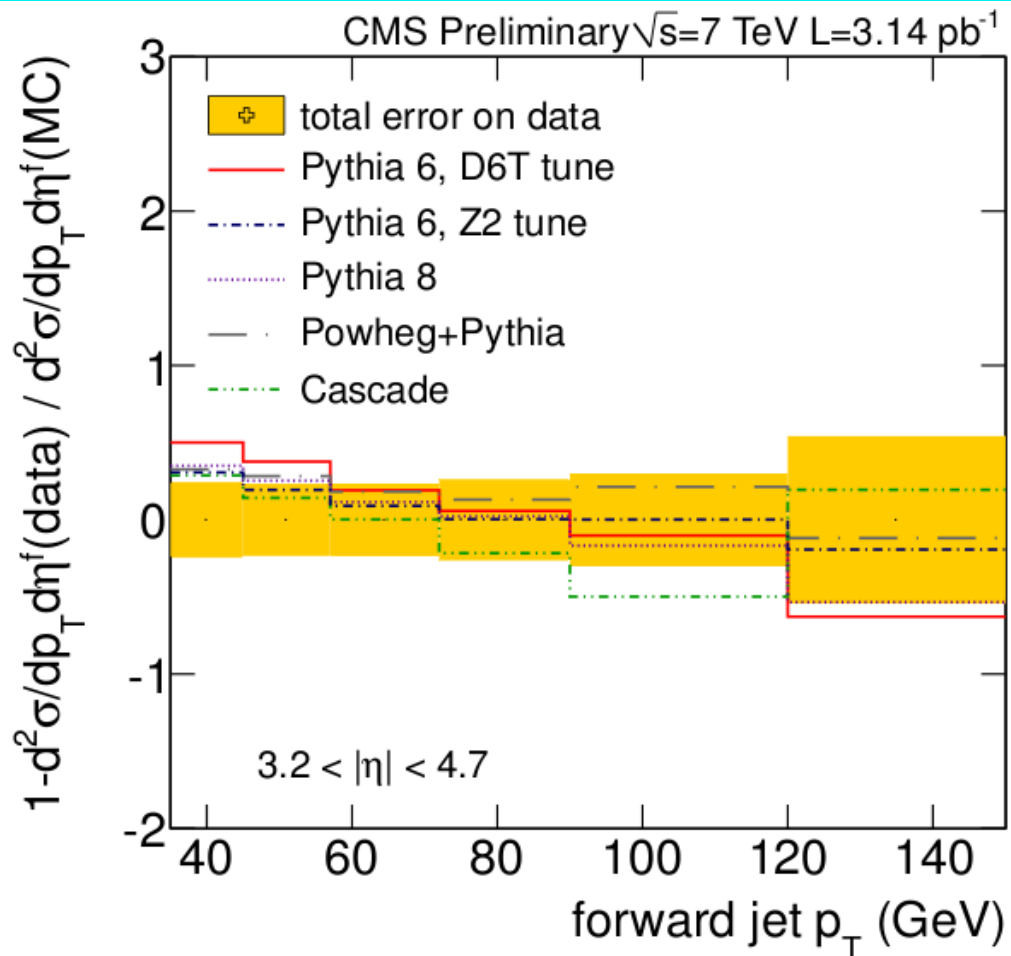
1 - ratio between measured cross section and MC



Good MC simulations

- Herwig+Jimmy
- Herwig++

- Powheg+Herwig
- HEJ



Not fair MC simulations

- Pythia
- Powheg+Pythia
- Cascade

Forward: low p_T jets

Central: normalization

- Luminosity collected **3.14 pb⁻¹** in pp at $\sqrt{s} = 7$ TeV CMS - LHC
- Forward jet production:
 - **Inclusive forward jet** production in the p_T [35-150] GeV/c and $3.2 < |\eta| < 4.7$
 - Perturbative calculations reproduce globally well the measured forward jet cross section
 - With decreased systematics \rightarrow low x test
 - Production of one **central** and one **forward** jet, p_T [35-150] GeV/c and $|\eta| < 4.7$.
 - Some calculations not in agreement with data



Backup



Event selection

- Beam halo event veto
- Beam scraping events veto
- Primary vertex with ≥ 10 tracks with $|z| < 24$ cm

Jet-ID

Remove unphysical energy deposit

- HF noise removal
- $n^{\text{hit}} > 1 + 2.4(\ln p_T^{\text{raw}} - 1)$ in $3.0 < |\eta| < 3.8$
- $n^{\text{hit}} > 1 + 3(\ln p_T^{\text{raw}} - 1)$ in $|\eta| \geq 3.8$
- $0.6 + 0.05 (\max(0, 9 - \ln E^{\text{raw}}))^{1.5} > \alpha_{\text{LS}} > -0.2 - 0.041 (\max(0, 7.5 - \ln E^{\text{raw}}))^{2.2}$
where α_{LS} is the fraction of electromagnetic component of the total jet energy